3-27-2015

3D Reconstruction of the Vascularity of a Stegosaurus Dorsal Plate and an Alligator Scute

Dan Deifenbaugh
Indiana University - Purdue University Fort Wayne

Benjamin Aeschliman
Indiana University - Purdue University Fort Wayne, aescbd01@ipfw.edu

Paul Barrett
Natural History Museum, Cromwell Road, London

Charlotte Brassey
Natural History Museum, Cromwell Road, London

Shoji Hayashi
Osaka Museum of Natural History Nagai Park, Japan

See next page for additional authors

Authors
Dan Deifenbaugh, Benjamin Aeschliman, Paul Barrett, Charlotte Brassey, Shoji Hayashi, and Beomjin Kim

Three Dimensional Reconstruction of the Vascularity of a Stegosaurus Dorsal Plate and an Alligator Scute

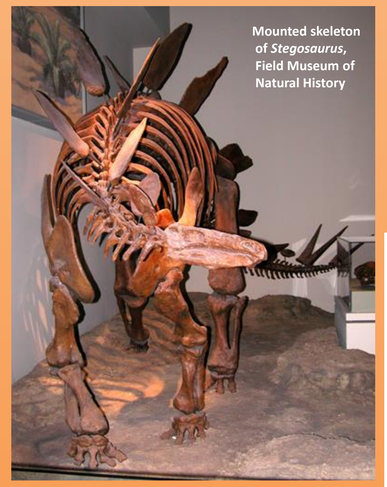
Dan Deifenbaugh: Department of Geosciences, Indiana-Purdue University Fort Wayne
Ben Aeschliman: Information Analytics and Visualization Center, Indiana-Purdue University Fort Wayne
Paul Barrett: Head of Division, Earth Sciences Department, Vertebrates and Anthropology Palaeobiology, Natural History Museum, Cromwell Road, London
Charlotte Brassey: Department of Earth Sciences Natural History Museum, Cromwell Road, London
James Farlow: Professor of Geology and Paleontology Department of Geosciences Indiana-Purdue University Fort Wayne
Shoji Hayashi: Osaka Museum of Natural History Nagai Park , 1-23, Higashi-Sumiyoshi-ku, Osaka, 546-0034, Japan
Beomjin Kim: Computer Science Department and Information Analytics and Visualization Center at Indiana University-Purdue University Fort Wayne

ABSTRACT

Three dimensional models of the dorsal plates of the thyreophoran dinosaur *Stegosaurus* and the osteoderms of an extant alligator (*Alligator mississippiensis*) were constructed utilizing 3D vision technology to study the potential vascular structures for the dermal ossifications of both species. 3D (stereoscopic) vision devices, which present two different images of a 3D object capture from the same projection plane, allow users to perceive depth from a rendered scene that is natural and intuitive to comprehend when compared with a 3D object rendered on a traditional 2D screen.

A system was developed that displays surface models of the each structure's exterior and the possible soft tissue areas of the interior. Cross section images were created from volumetric CT scan images, which had potential soft tissue areas highlighted using SPIERS software. The segmented volumetric data sets were transformed into triangular meshes using the Marching Cubes Algorithm. Phong shading was applied to the triangular meshes providing a surface model view from the CT scan images. The system superimposes two computer-generated surface models and a cross section image on two different viewpoints to render a stereoscopic view of the *Stegosaurus* dorsal plate and the American alligator scute.

The system provides several interactive data analysis tools which enable users to navigate the dermal plates of *Stegosaurus* in virtual spaces from various directions, locate the slicing plane for cross section images, and magnify areas of interest. The system allows users to analyze internal structures of fossils while referencing associated exterior surface models and cross-sectional images in stereoscopic vision. The models of the *Stegosaurus* dorsal plate and alligator scute allow users to visualize soft tissue/vascular areas that could have facilitated blood flow between the osteoderm and the animals' interior, possibly allowing for thermal regulation.


Mounted skeleton of *Stegosaurus*, Field Museum of Natural History

Introduction

The thyreophoran dinosaur *Stegosaurus* is well known for its dermal ossifications in the form of dorsal plates and tail spikes. Various researchers have observed large openings at the base of the dorsal plates of *Stegosaurus,* which penetrate into the interior of the plate, and have interpreted these openings as "pipes" which may have contained blood vessels to facilitate perfusion throughout a plate's structure (Farlow et al. 1976; Buffrénil et al. 1986; cf. Main et al. 2005). These results are consistent with earlier interpretations of *Stegosaurus* plates having a thermoregulatory function.
Two dimensional images on a flat surface have limitations for a researcher trying to visualize the internal configuration of a specimen with complicated interior features, so we developed 3D models from CT scans of both a *Stegosaurus* dorsal plate and a modern analogue, the osteodermal scute of an *Alligator.* These 3D images are more natural and intuitive for the viewer than 2D images (Zelle and Figura 2004).

Materials and Methods

CT scans of both specimens were imported into the Serial Palaeontological Image Editing and Rendering System (SPIERS) software, which allows users to mark tomographic data sets, such as CT image slices, and convert them to 3D models (Sutton and Russell Garwood 2014). Here the process involved analyzing CT scans of both specimens, looking for regions of reduced density which appear as darker areas of the image. Those areas of reduced density which appear to follow distinct, observable channels from either the base or the exterior surface to the interior were highlighted with SPIERS software. Only the most prominent channels were highlighted.

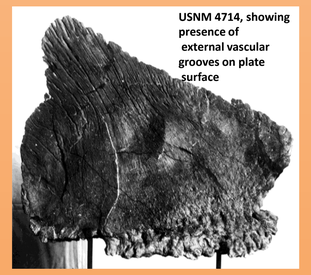
Three-dimensional representations of both specimens were created by using a system that displays two different models for each specimen and cross sectional images that are created based on user-specified arbitrary angles. One model shows the exterior, and the other is a surface model of the segmented "pipes." Cross section images were reconstructed from volumetric CT scan images modified in SPIERS. These volumetric data sets consist of multiple 2D image slices. There were 41 image slices for the *Stegosaurus* plate, and 153 image slices for the *Alligator* scute. Each slice of the alligator scute has a dimension of 512 by 512 pixels, and each slice of the stegosaur plate has a dimension of 944 by 563 pixels; both models have 8 bits per pixel. For surface model generation, contour lines are defined separating each image slice into different areas based on density. The Marching Cubes Algorithm was applied to the segmented volumetric data sets, which transforms them into triangular meshes (Lorensen and Cline 1987). The application of Phong shading to the triangular meshes provides a surface model view from the CT scan images (Phong 1975). Finally, the system superimposes two computer-generated surface models, and a cross section image on two different viewpoints, to render a stereoscopic view of the dermal ossifications of the animals.

Results

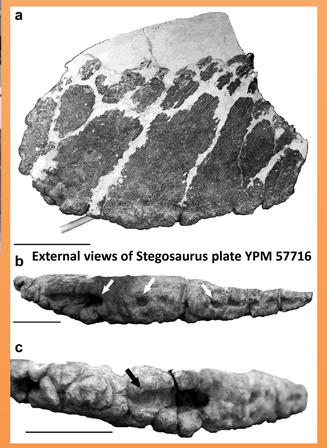
Both models depict regions of deduced density, starting at points at the base of the structures and extending to the interior. These open spaces or "pipes" spread out to the exterior surface at multiple locations in the *Alligator* scute. The *Stegosaurus* dorsal plate has channels extending up from the base into a "vestibule" that runs lengthwise from the anterior to the posterior of the plate. This vestibule has pipes which branch up apically into the structure. The *Stegosaurus* plate also has smaller channels that extend out to the surface, which in at least one instance connect to surface grooves which may have been part of the external dermal vasculature. The ability to manipulate 3D models of internal vascularity provides better understanding of the structure of this system.

Future research

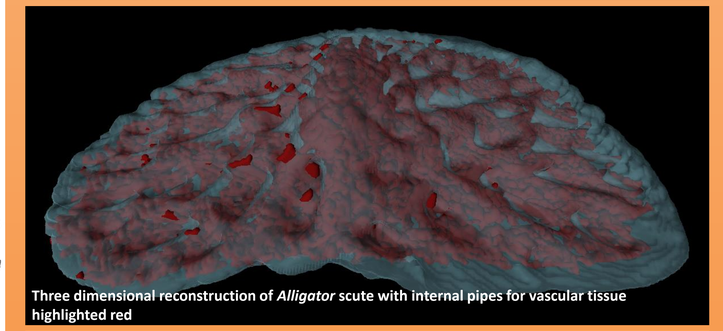
This approach will be extended to a larger sample of stegosaur plates and tail spikes, to see how consistent the internal patterns of vasculature are. We will examine plates and spikes from a particularly complete specimen in the Natural History Museum (London) (Brassey et. al. 2015) and specimens in other collections (Hayashi et al. 2012).


USNM 4714, showing presence of external vascular grooves on plate surface

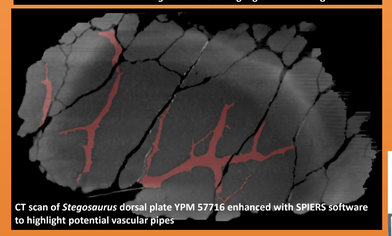

Stegosaurus (Bob Walters & Tess Kissinger, Carnegie Museum of Natural History)

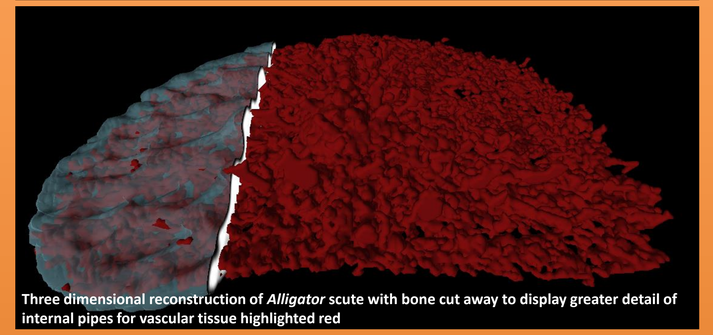


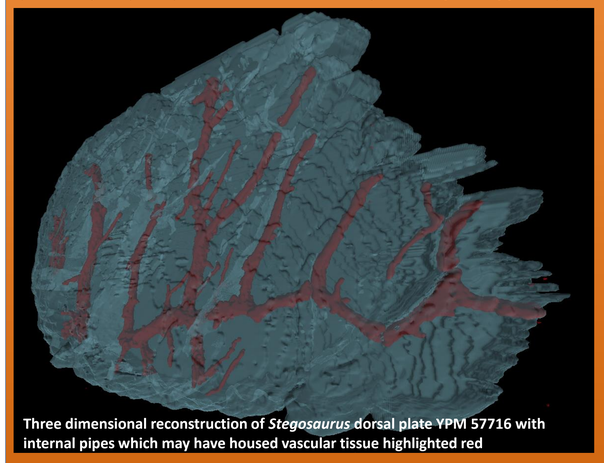
External views of Stegosaurus plate YPM 57716

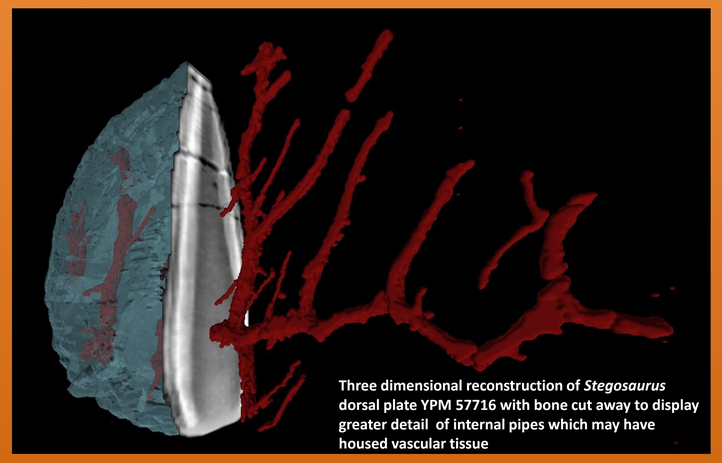

Three dimensional reconstruction of *Alligator* scute with internal pipes for vascular tissue highlighted red

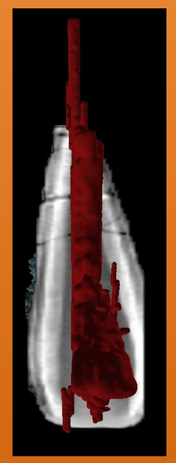
SPIERS enhanced CT scan of *Alligator* scute to highlight vascular regions


CT scan of *Stegosaurus* dorsal plate YPM 57716 enhanced with SPIERS software to highlight potential vascular pipes


Three dimensional reconstruction of *Alligator* scute with bone cut away to display greater detail of internal pipes for vascular tissue highlighted red


Three dimensional reconstruction of *Stegosaurus* dorsal plate YPM 57716 with internal pipes which may have housed vascular tissue highlighted red


Three dimensional reconstruction of *Stegosaurus* dorsal plate YPM 57716 with bone cut away to display greater detail of internal pipes which may have housed vascular tissue


Transverse section through potential vascular region of Yale plate

Neck plate and tail spikes of NHMUK R36730. CT scans from this and other *Stegosaurus* specimens will be compared with our models made from the Yale specimen in further work

Brassey, C. A., Maidment, S. C., and Barrett, P. M. (2015). *Biology Letters*, 11(3), 20140984
Buffrénil, V. de, Farlow, J. O., and Ricqlès, A. de (1986). *Paleobiology*, 12, 459–473
Garwood, R. J., and Sutton, M. D. (2014). *SPIERSedit 2.20, Serial Palaeontological Image Editing and Rendering System: Specimen Interpretation and Editing Tool Users Manual*. 3
Farlow, J. O., Thompson, C. V., and Rosner, D. E. (1976). *Science*, 192, 1123–1125
Farlow, J. O., Hayashi, S., and Tattersall, G. J. (2010). *Swiss Journal of Geosciences*, 103(2), 173 –185
Hayashi, S., Carpenter, K., Watabe, M., Mc Whinney, L. A. (2012). Paleontology 55: 145-161
Lorensen, W. E., and Cline, H. E. (1987, August). In ACM siggraph computer graphics (Vol. 21, No. 4, pp. 163-169). ACM
Main, R. P., Ricqles, A. de, Horner, J. R., and Padian, K. (2005). *Paleobiology*, 31, 291–314
Phong, B. T., Communications of ACM, 18(6), pp. 311–317, 1975
Zelle, J. M., and Figura, C. (2004). ACM SIGCSE Bulletin, 36(1), 348-352

INDIANA UNIVERSITY • PURDUE UNIVERSITY IPFW • FORT WAYNE